ibration data. The software is capable of timing events as well as running scripts for semi-autonomous operation. The software also records this variety of data with proper timing.

This complex software package is composed of two primary parts: hardware communications and user interfacing. The hardware interfacing section allows for the computer to transfer data and commands (via digital or analog signals) to a wide variety of system components such as sensors, valves, transducers, analyzers, pumps, etc. The hardware interfacing section also allows for the recording of the transferred data/commands to be stored on the local computer. The user interface section gathers the data from the hardware interfacing section and presents it to the user in various user-configurable methods. The two most common methods of providing data to the user are via time-domain charting and real-time parameter value/status.

This work was done by C. Arkin, Charles Curley, Eric Gore, David Floyd, and Damion Lucas of Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13643

Miniaturized Laser Heterodyne Radiometer (LHR) for Measurements of Greenhouse Gases in the Atmospheric Column

Instrument could be used to validate other Earth observing missions.

Goddard Space Flight Center, Greenbelt, Maryland

This passive laser heterodyne radiometer (LHR) instrument simultaneously measures multiple trace gases in the atmospheric column including carbon dioxide (CO_2) and methane (CH_4), and resolves their concentrations at different altitudes. This instrument has been designed to operate in tandem with the passive aerosol sensor currently used in AERONET (an established network of more than 450 ground aerosol monitoring instruments worldwide). Because aerosols induce a radiative effect that influences terrestrial carbon exchange, simultaneous detection of aerosols with these key carbon cycle gases offers a uniquely comprehensive measurement approach.

Laser heterodyne radiometry is a technique for detecting weak signals that was adapted from radio receiver technology. In a radio receiver, a weak input signal from a radio antenna is mixed with a stronger local oscillator signal. The mixed signal (beat note, or intermediate frequency) has a frequency equal to the difference between the input signal and the local oscillator. The intermediate frequency is amplified and sent to a detector that extracts the audio from the signal.

In the LHR instrument described here, sunlight that has undergone absorption by the trace gas is mixed with laser light at a frequency matched to a trace gas absorption feature in the infrared (IR). Mixing results in a beat signal in the RF (radio frequency) region that can be related to the atmospheric concentration. For a one-second integration, the estimated column sensitivities are 0.1 ppmv for CO_2, and <1 ppbv for CH_4.

In addition to producing a stand-alone ground measurement product, this instrument could be used to calibrate/validate four Earth observing missions: ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons), OCO-2 (Orbiting Carbon Observatory), OCO-3, and GOSAT (Greenhouse gases Observational SATellite).

The only network that currently measures CO_2 and CH_4 in the atmospheric column is TCCON (Total Carbon Column Observing Network), and only two of its 16 operational sites are in the United States. TCCON data is used for validation of GOSAT data, and will be used for OCO-2 validation. While these Fourier-transform spectrometers (FTS) can measure the largest range of trace gases, the network is severely limited due to the high cost and extreme size of these instruments (these occupy small buildings and require personnel for operation). The LHR/AERONET instrument offers a significantly smaller (carry-on luggage size) autonomous instrument that can be incorporated into AERONET's much larger (450 instruments) global network.

This work was done by Emily Steel and Matthew McLinden of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16327-1

Anomaly Detection in Test Equipment via Sliding Mode Observers

Commercial applications of the algorithms exist in the oil, natural gas, and chemical industries for identifying and localizing leaks.

Stennis Space Center, Mississippi

Nonlinear observers were originally developed based on the ideas of variable structure control, and for the purpose of detecting disturbances in complex systems. In this anomaly detection application, these observers were designed for estimating the distributed state of fluid flow in a pipe described by a class of advection equations.

The observer algorithm uses collected data in a piping system to estimate the distributed system state (pressure and velocity along a pipe containing liquid gas propellant flow) using only boundary measurements. These estimates are then used to further estimate and localize possible anomalies such as leaks or foreign objects, and instrumentation metering problems such as incorrect flow meter orifice plate size.

The observer algorithm has the following parts: a mathematical model of the fluid flow, observer control algorithm, and an anomaly identification algorithm. The main functional operation of the algorithm is in creating the sliding mode in the observer system implemented as software. Once the sliding mode starts in the system, the equivalent value of the discontinuous function in sliding mode can be obtained by filtering out the high-frequency chattering component. In control theory, "observers" are dynamic algorithms for the online estimation of the current state of a dynamic system by measurements of an output of the system. Classical linear observers can provide optimal estimates of a system state in case of uncertainty modeled by white noise. For nonlinear cases, the theory of nonlinear observers has been developed and its success is mainly due to the sliding mode approach.

Using the mathematical theory of variable structure systems with sliding modes, the observer algorithm is designed in such a way that it steers the output of the model to the output of the system obtained via a variety of sensors, in spite of possible mismatches between the assumed model and actual system. The unique properties of sliding mode control allow not only control of the model internal states to the states of the real-life system, but also identification of the disturbance or anomaly that may occur.

This work was done by Wanda M. Solano of Stennis Space Center and Sergey V. Drakunov of Embry-Riddle Aeronautical University. For more information, call the Innovative Partnerships Office at 228-688-1929. SSC-00369

Absolute Position of Targets Measured Through a Chamber Window Using Lidar Metrology Systems

This technique can be used to measure objects in thermal-vacuum chamber test environments, in furnaces used to forge items for manufacturing, and for measuring chemically volatile or radioactive materials through a window.

Goddard Space Flight Center, Greenbelt, Maryland

Lidar is a useful tool for taking metrology measurements without the need for physical contact with the parts under test. Lidar instruments are aimed at a target using azimuth and elevation stages, then focus a beam of coherent, frequency modulated laser energy onto the target, such as the surface of a mechanical structure. Energy from the reflected beam is mixed with an optical reference signal that travels in a fiber path internal to the instrument, and the range to the target is calculated based on the difference in the frequency of the returned and reference signals. In cases when the parts are in extreme environments, additional steps need to be taken to separate the operator and lidar from that environment. A model has been developed that accurately reduces the lidar data to an absolute position and accounts for the three media in the testbed — air, fused silica, and vacuum — but the approach can be adapted for any environment or material.

The accuracy of laser metrology measurements depends upon knowing the parameters of the media through which the measurement beam travels. Under normal conditions, this means knowledge of the temperature, pressure, and humidity of the air in the measurement volume. In the past, chamber windows have been used to separate the measuring device from the extreme environment within the chamber and still permit optical measurement, but, so far, only relative changes have been diagnosed. The ability to make accurate measurements through a window presents a challenge as there are a number of factors to consider.

In the case of the lidar, the window will increase the time-of-flight of the laser beam causing a ranging error, and refract the direction of the beam causing angular positioning errors. In addition, differences in pressure, temperature, and humidity on each side of the window will cause slight atmospheric index changes and induce deformation and a refractive index gradient within the window. Also, since the window is a dispersive media, the effect of both phase and group indices have to be considered. Taking all these factors into account, a method was developed to measure targets through multiple regions of different materials and produce results that are absolute measurements of target position in three-dimensional space, rather than simply relative position.

The environment in which the lidar measurements are taken must be broken down into separate regions of interest and each region solved for separately. In this case, there were three regions of interest: air, fused silica, and vacuum. The angular position of the target inside the chamber is solved using only phase index and phase velocity, while the ranging effects due to travel from air to glass to vacuum/air are solved with group index and group velocity. When all parameters are solved simultaneously, an absolute knowledge of the position of each target within an environmental chamber can be derived.

Novel features of this innovation include measuring absolute position of targets through multiple dispersive and non-dispersive media, deconstruction of lidar raw data from a commercial off-the-shelf unit into reworkable parameters, and use of group velocities to reduce range data. Measurement of structures within a vacuum chamber or other harsh environment, such as a furnace, may now be measured as easily as if they were in an ambient laboratory. This analysis permits transformation of the raw data into absolute spatial units (e.g., mm).

This technique has also been extended to laser tracker, theodolite, and cathetometer measurements through refractive media.

This work was done by David Kubalak, Theodore Hadjimichael, and Raymond Ohl of Goddard Space Flight Center; Anthony Slotwinski of Nikon Metrology; Randal Telfer of Orbital Sciences Corp.; and Joseph Hayden of Sigma Space Corp. Further information is contained in a TSP (see page 1). GSC-16192-1